

Heart Rate Variability Predicts Self-Control in Goal Pursuit

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Abstract

The aim of our study was to investigate the effects of a failure experience on the exercise of self-control in goal pursuit. We hypothesized that tonic heart rate variability (tonic HRV), a possible physiological marker of inhibitory capacity, increases the exercise of self-control in the pre- and post-actional phase in goal pursuit after failure. Participants received feedback for an alleged intelligence test and subsequently worked on the same test again. As indicators of exercised self-control, we assessed self-confidence in the pre-actional phase and rumination in the post-actional phase. As hypothesized, tonic HRV was positively associated with pre- and post-actional self-control, even after controlling for the effect of neuroticism. We discuss the implications of our results for the self-regulatory strength model. Copyright © 2009 John Wiley & Sons, Ltd.

Key words: heart rate variability; self-regulatory strength; ruminative thinking

INTRODUCTION

If you do not succeed, can you control yourself and confidently try again? If you have failed, can you control yourself and not think about the failure all the time? A limited resource termed self-regulatory strength may determine if you are able to exercise self-control in the face of failure (Baumeister, Vohs, & Tice, 2007). People differ in their general level of self-regulatory strength (Muraven & Baumeister, 2000), resulting in interindividual differences in self-control across a variety of spheres (Baumeister & Heatherton, 1996). Furthermore, acts of self-control may impair subsequent self-control due to temporary exhaustion of self-regulatory strength. A key feature of self-regulatory strength is inhibitory capacity (Muraven & Baumeister, 2000).

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Self-control in goal pursuit after failure

The course of goal pursuit can be divided into three phases (Gollwitzer, 1990): the *pre-actional* phase in which goal-directed action is initiated, the *actional* phase in which goal directed behaviour is performed and the *post-actional* phase in which the actual outcome is compared with the intended goal. So far research on self-control and failure has concentrated on overt behaviour during the action phase. Results show that persistence in the face of failure requires self-control and draws on self-regulatory strength (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Muraven, Tice, & Baumeister, 1998; Segerstrom & Nes, 2007). The purpose of our study was to cast light on self-control in the pre-and post-actional phase of goal pursuit. Our research question was: given a prior failure experience, will self-regulatory strength have an impact on self-control during following pre- and post-actional phases?

Motivation in the pre-actional phase

In Gollwitzer's model of action phases (Gollwitzer, 1990), the motivational force at work in the pre-actional phase is specified as volitional strength: the strength of the commitment to actually strive for a goal—even under conditions of frustration and stress, such as the experience of failure. Acts of volition are acts of self-control (Muraven & Baumeister, 2000). To assess self-control in the pre-actional phase, we measured a cognitive-affective aspect of self-control—self-confidence (Kuhl & Fuhrmann, 1998). During the pre-actional phase, successfully exercised self-control should manifest in high levels of self-confidence, while low self-control should manifest in low levels of self-confidence. In a similar vein, Dweck and Legget (1988) distinguish a maladaptive affective reaction to a setback, characterized by anxiety and shame, from an adaptive affective reaction to setback, characterized by pride and determination. Both affective reactions are indicative of a low versus high level of self-confidence. Hence, after a failure experience, reported self-confidence may serve as an indicator of self-control in the pre-actional phase of the action to come.

Rumination in the post-actional phase

Failure experience—not having reached a set goal—foster perpetuating goal-related thoughts (Koole, Smeets, van Knippenberg, & Dijksterhuis, 1999). This ruminative thinking is repetitive, uncontrollable and sometimes aversive. It is characterized by concomitant negative affect, as it generally focuses on contents associated with the failure to make progress towards reaching the goal (Segerstrom, Stanton, Alden, & Shortridge, 2003). The cognitive representation of an unattained goal automatically shows increased activation in long-term memory (Goschke & Kuhl, 1993). Along similar lines, Martin and Tesser (2006) and Martin, Shrira, and Startup (2004) posit that heightened accessibility of goal-related information is the cognitive mechanism underlying rumination. Consequently, a failure experience—that is not reaching a goal—should automatically activate goal representation. To stop or prevent the automatic response of ruminating after failure it is necessary to exercise self-control. Hence, after a failure experience, self-control in the post-actional phase should manifest in less ruminative thinking.

Assessing self-regulatory strength

It is not possible for an individual to directly report his state or trait level of self-regulatory strength (Muraven & Baumeister, 2000). To assess self-regulatory strength, we therefore

employed a physiological index. Self-regulatory strength has many facets, and one of its key features is the capacity for inhibition (Muraven & Baumeister, 2000). A promising candidate that could serve as a physiological marker of an individual's capacity for inhibition—is *tonic heart rate variability* (tonic HRV; Baumeister et al., 2007; Segerstrom & Nes, 2007). Tonic HRV refers to beat-to-beat variation in heart rate produced by the interplay of sympathetic and parasympathetic (vagal) activity. Especially high-frequent, vagal mediated tonic HRV is thought to be a peripheral proxy for inhibitory strength (Thayer & Friedman, 2002). The link between tonic HRV and inhibitory capacity is supported by several findings concerning response inhibition (Hansen, Johnsen, & Thayer, 2003), repetitive thinking (Brosschot, Van Dijk, & Thayer, 2006; Thayer & Lane, 2002) and disinhibited anger expression (Dorr, Brosschot, Sollers, & Thayer, 2007). Moreover, research has shown an association between HRV and clinical disorders, such as substance abuse, antisocial tendencies in prison inmates or binge eating, where disinhibited thoughts and actions are key features (Friederich et al., 2008; Hansen, Johnsen, Thornton, Waage, & Thayer, 2007; Ingjaldsson, Laberg, & Thayer, 2003). Appelhans and Luecken (2006) even claim that tonic HRV could serve as an objective measure of emotion regulation, generating emotional responses of appropriate time and magnitude, which involves inhibition.

Neuroticism and self-control

An individual scoring high in neuroticism perceives the world as more threatening, experiences higher levels of stress (Watson, Clark, & Harkness, 1994) and is more sensitive to negative emotional states (Larsen & Ketelaar, 1991) than is an individual scoring low on this trait. Furthermore, neuroticism is negatively associated with habitual coping strategies that are characterized by exercised self-control, such as planning, reinterpretation and active coping. By contrast, neuroticism is positively associated with dispositional coping strategies that are characterized by low self-control, such as venting of emotions and behavioural disengagement (Ferguson, 2001). Thus, with respect to coping outcomes and the habitual use of coping strategies, neuroticism is negatively related to the exercise of self-control. Moreover, there is evidence to suggest that rumination is related to neuroticism, or that a ruminative response style could even be considered a cognitive manifestation of neuroticism (see Roelofs, Huibers, Peeters, & Arntz, 2008). It is less clear, however, whether neuroticism influences self-confidence. The association between dispositional coping strategies and neuroticism described above suggests a negative impact of neuroticism on self-confidence.

Thus, it is to be expected that trait neuroticism will influence self-control—more specifically, rumination and self-confidence—during the pre- and post-actional phases following a failure experience. Interindividual differences in neuroticism thus may obscure links between an individual's inhibitory capacity and self-control. The important question is whether inhibitory capacity will increase self-control after controlling for the effect of neuroticism. In other words, is the explanatory power of inhibitory capacity already captured by neuroticism? Evidence for unique effects of trait neuroticism and self-regulatory strength on psychopathological symptoms in non-clinical adolescents (Muris, 2006) suggests that there could be a unique effect of self-regulatory strength on self-control during goal pursuit, independent of the effect of neuroticism.

THE PRESENT STUDY

Exercised self-control depends on an individual's inhibitory capacity. After a failure experience, the cognitive-affective aspect of self-control manifests in higher self-confidence in the pre-actional phase and in less ruminative thinking in the post-actional phase. We hypothesize that after a failure experience, one's inhibitory capacity (1) increases self-confidence during the pre-actional phase and (2) decreases ruminative thinking during the post-actional phase.

To test these hypotheses, we induced a failure experience through feedback on an alleged intelligence test. Subsequently, we assessed ruminative thinking about the intelligence test (post-actional phase). Next, we assessed self-confidence after asking participants to complete the same intelligence test again (pre-actional phase).

METHODS

Psychology students ($N=53$, % female = 94¹; age $M=21.55$ years, $SD=2.67$) were given course credit to compensate for participation. Inhibitory capacity was assessed via tonic HRV, and level of neuroticism via self-report. Participants were randomly assigned to either the failure feedback or the success feedback condition. The other independent variables were inhibitory capacity, neuroticism and feedback. The dependent variables were ruminative thinking and self-confidence.

Procedure

The experimental session began with an alleged intelligence test, on which participants received bogus feedback. Thereafter, a task unrelated to this study followed for an average of 15 minutes.² This time window was chosen to enable individual differences in self-regulatory strength to take effect. We then assessed rumination: first, we measured the mechanisms underlying rumination (i.e. activation of goal representation) and then the experience of rumination. Subsequently, participants were informed that they would once more be working on the same intelligence test on which they had received feedback. Before participants actually completed on this test again, we assessed their self-confidence. Finally, we debriefed participants.

Independent measures

Feedback

We administered the alleged intelligence test on a computer. It comprised 10 verbal analogies in consecutive order. Participants were instructed to find the two missing words in each analogy by choosing from a list of five words presented on the bottom half of the screen. The response time was limited to 1 minute. Participants were forced to make an entry in order to make the alleged results plausible. However, all analogies were unsolvable. The alleged result in the failure feedback condition was two right answers out

¹All statistical analyses without the three male participants yielded the same results.

²The feedback condition had no significant influence on time spent on the unrelated task, and tonic HRV did not correlate significantly with time spent on the unrelated task in either feedback condition.

of ten. In the success feedback condition, the alleged result was eight right answers out of ten. Participants had to write down their score underneath the written instructions to assure that they took notice of the alleged results.

Inhibitory capacity

Inhibitory capacity was assessed via tonic HRV. Before the experimental session started, we measured heart rate via the heart rate monitoring system Polar S810i (Polar Electro Oy, Kempele, Finland). During this 6 minutes measurement, participants sat still without distraction, as parasympathetic influences predominate at rest. Using the Polar Precision Performance™ Software, we pre-processed sequential interbeat intervals for artefacts. A visual screening for artefacts followed. We then used the HRV Analysis program (Niskanen, Tarvainen, Ranta-oha, & Karjalainen, 2004) to perform a frequency-based technique of power spectral analysis (autoregressive modelling technique) to extract high-frequency components, 0.15–0.4 Hz, which primarily reflect cardiac parasympathetic influence from sequential interbeat intervals. The absolute value of power was chosen as unit (ms^2); following we took the logarithm. Similarly, we processed heart rate data from a second rest phase directly after the experimental session to calculate retest-reliability, $r = .70$, $p < .01$.

Neuroticism was assessed with the seven items from the neuroticism scale of the Big Five Inventory (BFI; John & Sirvastava, 1999; Lang, Lüdtke, & Asendorpf, 2001). The response format ranged from 1 ‘not at all true’ to 5 ‘totally true’. Cronbach’s α was .87. We averaged item responses to obtain scale scores.

Dependent measures

Rumination

To measure rumination about the alleged intelligence test, we assessed two aspects: the activation of goal representation (as the mechanism underlying rumination; Martin & Tesser, 2006) and the subjective experience of rumination.

Activation of goal representation

We operationalized activation of goal representation as a faster response in a computerized lexical decision task to words related to intelligence than to words not related to intelligence (*cf.* Koole et al., 1999). Measuring intelligence is the alleged purpose of the analogy test. However, activation of representations related to intelligence is dysfunctional for successful work on the analogies, as representations related to intelligence are not involved in solving the analogies (Mikulincer, 1989; Sarason, Pierce, & Sarason, 1996; Vallacher & Wegner, 1987).

On a computer screen, participants were presented with a word or a random string of letters without semantic content. By pressing marked keys on the keyboard, participants had to indicate as quickly as possible if what they saw was a word or a string of letters. A word was indicated by pressing a right key, and a random string of letters was indicated by pressing a left key. The test comprised 29 strings and 29 words presented in random order. The first two words and the first two strings were not taken into account. All words were adjectives for describing personality (taken from Goldberg, 1990). Nine adjectives described an intelligent person, nine adjectives were of positive valence and served as control words, and nine adjectives were of negative valence and served as distracters. We chose positive adjectives as control words, since adjectives describing an intelligent person

are positively valenced and, in conjunction with emotional state, the valence of a word affects lexical processing (Ferraro, King, Ronning, Pekarski, & Risan, 2003).

Experience of rumination

We assessed the following aspects of experiencing rumination with 10 items: intrusive thought (e.g. 'I thought of the intelligence test while working on other tasks'), evaluative thought (e.g. 'I thought about the quality of my performance on the intelligence test'), reflective thought (e.g. 'I thought about how I felt because of my performance on the intelligence test') and generalized memory (e.g. 'I thought about other occasions where I felt the same because of my performance in a test'). On an 11-point scale ranging from 0 'not at all true' to 10 'totally true', participants rated the degree to which the respective statements described their thoughts. These thoughts could interfere with solving the analogies. One overall rumination score was computed by averaging across the different aspects. Cronbach's α was .88.

Self-confidence

On an 11-point scale ranging from 0 'not true' to 10 'totally true', participants rated 18 items based on Roseman, Wiest, and Swartz (1994). Each item began with the words, 'I feel...' The items were designed to capture the phenomenology of affect postulated by Dweck and Legget (1988) to represent adaptive and maladaptive affective reactions to challenge. We averaged six out of eighteen items (uncomfortable—reversed, self-conscious—reversed, small—reversed, determined, proud, confident) to compute one self-confidence score. Cronbach's α = .80.

RESULTS

Inhibitory capacity and neuroticism

At the trait level tonic HRV ($M = 5.13 \text{ ms}^2$, $SD = 1.64$) and neuroticism ($M = 3.00$, $SD = 0.79$) were significantly negatively associated, $r = -.36$, $p < .01$.

Self-confidence in the pre-actional phase

Failure feedback had a small, but non-significant influence on self-confidence in the pre-actional phase. After failure feedback, self-confidence scores were lower than after success feedback, $t(49) = -1.37$, $p = .18$, $d = -.38$; $M_{\text{failure}} = 5.66$, $SD = 1.99$ versus $M_{\text{success}} = 6.34$, $SD = 1.53$.

Results support the hypothesis that one's capacity of inhibition increases self-confidence in the pre-actional phase after a failure experience. Tonic HRV was significantly positively correlated with self-confidence scores after failure, but not after success feedback (Table 1). The correlations differed significantly between the two feedback conditions, $z = 1.71$, $p_{\text{one-tailed}} < .05$.

Neuroticism had no influence on self-confidence in the pre-actional phase. Neuroticism and self-confidence scores did not correlate in either of the feedback conditions (see Table 1).

Rumination in the post-actional phase

We assessed the mechanism underlying rumination—activation of goal representation—via a lexical decision task. The dependent variable was the mean reaction time difference

Table 1. Correlations of self-regulatory strength with rumination and self-confidence after failure feedback and after success feedback

		Rumination		
	<i>M</i> (SD)	Goal activation	Experienced rumination	Self-confidence
Failure feedback (<i>n</i> = 25)				
Neuroticism	2.99 (.78)	.31	.45*	−.07
Tonic HRV	4.65 (1.94)	−.49*	−.48*	.63**
Success feedback (<i>n</i> = 26)				
Neuroticism	3.01 (.82)	−.10	.23	−.02
Tonic HRV	5.59 (1.16)	−.01	.00	.22

* $p < .05$; ** $p < .01$.

between control and intelligence words. Mean reaction time to intelligence words was subtracted from reaction time to control words. Thus, higher values indicate more rumination. We excluded errors (e.g. identifying a word as a string) when computing the dependent variable.³ Experience of rumination was assessed via self-report.

Both rumination indices were sensitive to failure feedback. In comparison to success feedback, failure feedback led to significantly higher rumination scores on both indices (goal activation: $t(49) = 2.44$, $p < .05$, $d = .68$; $M_{\text{failure}} = 37.51$ milliseconds, $SD = 110.87$ versus $M_{\text{success}} = -39.14$ milliseconds, $SD = 113.81$; experienced rumination: $t(50) = 3.04$, $p < .01$, $d = .85$; $M_{\text{failure}} = 5.60$, $SD = 2.49$ versus $M_{\text{success}} = 3.80$, $SD = 1.69$). Furthermore, the two rumination indices were significantly correlated after failure feedback, $r = .42$, $p < .05$, but not after success feedback, $r = -.13$, $p = .54$.

Results support the hypothesis that inhibitory capacity decreases ruminative thinking in the post-actional phase after failure experience. Tonic HRV was significantly negatively correlated with goal activation and experienced rumination after failure feedback, but not after success feedback (see Table 1). The correlations differed significantly between the feedback conditions, $z = 1.75$, $p_{\text{one-tailed}} < .05$, and $z = 1.73$, $p_{\text{one-tailed}} < .05$, respectively.

As expected, neuroticism also influenced ruminative thinking in the post-actional phase after failure experience. Neuroticism scores were positively correlated with both rumination indices after failure feedback (see Table 1). To examine whether trait HRV had an influence on ruminative thinking following a failure experience even when controlling for the effect of neuroticism, we performed a regression analysis with the predictor tonic HRV in the failure feedback condition to predict residual rumination indices with neuroticism scores partialled out. Tonic HRV significantly predicted goal activation residual scores, $\text{adj. } R^2 = .16$, $F(1,22) = 5.46$, $p < .05$, $\beta = -.45$. However, tonic HRV did not significantly predict experienced rumination residual scores, $\text{adj. } R^2 = .05$, $F(1,23) = 2.33$, $p = .14$, $\beta = -.30$. Thus, it can be concluded that after a failure experience, inhibitory strength explains variance in the activation of goal representation (i.e. the postulated mechanism underlying rumination) that is not accounted for by

³Errors were evenly distributed over feedback conditions, $t(49) = -.79$, $p = .43$, $M_{\text{failure}} = .32$, $SD = .56$ versus $M_{\text{success}} = .46$, $SD = .71$. Sample size reduction was due to logfile loss because of technical difficulties and the exclusion of the data from one participant, who misunderstood the instructions in the lexical decision task. This misunderstanding resulted in extremely long reaction times. Furthermore, tonic HRV did not correlate with errors in either feedback condition.

neuroticism. In the experience of ruminative thought however, inhibitory strength did not explain additional variance over and above the variance explained by neuroticism.

DISCUSSION

The purpose of our study was to examine the impact of self-regulatory strength on self-control in the pre- and post-actional phase after a failure experience. In the pre- as well as in the post-actional phase we assessed cognitive-affective manifestations of self-control, self-confidence and rumination. We assessed a key feature of self-regulatory strength, inhibitory capacity. We operationalized inhibitory capacity by tonic HRV. As hypothesized, inhibitory capacity (1) increased self-confidence during the pre-actional phase, and (2) decreased ruminative thinking during the post-actional phase. Both increased self-confidence and decreased ruminative thinking are treated as dysfunctional. We argue for the dysfunctionality of ruminative thinking as assessed by the experience of rumination measure as follows. If goal representations are not relevant for ongoing activity, goal representations are off-task cognitions that may impair performance (Mikulincer, 1989; Sarason, Pierce, & Sarason, 1996). Furthermore, rumination predicts depression, anxiety, stress and anger (Garnefski & Kraaij, 2006; Martin & Dahlen, 2005).

These results expand our knowledge of the effect of self-regulatory strength after a failure experience. Following a failure experience, self-regulatory strength not only enables self-control during the actional phase (*cf.* Baumeister et al., 1998; Muraven et al., 1998; Segerstrom & Nes, 2007), but also during the pre- and post-actional phase of goal pursuit. The questions remain (a) whether self-regulatory strength also effects self-control of overt behaviour in the pre- and post-actional phase, such as inhibiting other behaviour in order to prepare for the target action (pre-actional) or in order to evaluate past action (post-actional); (b) whether self-regulatory strength also effects cognitive-affective manifestations of self-control during the actional phase, such as the feeling of commitment.

Three implications for the self-regulatory strength model (Baumeister et al., 2007) can be drawn from our results. First, tonic HRV connects the concept of self-regulatory strength to neurobiological mechanisms of inhibition (Thayer & Friedman, 2002; Vohs & Heatherton, 2000), insofar as inhibitory capacity can be measured by tonic HRV, and inhibitory capacity is one key aspect of self-regulatory strength.

Second, we demonstrated that even after controlling for neuroticism, inhibitory capacity predicted self-control. Inhibitory capacity uniquely affected self-confidence when participants were about to work on a task on which they had failed previously and reduced automatic activation of goal representation after failure. Notably, the experience of rumination after failure was mainly influenced by neuroticism. This finding is in line with the view that neuroticism constitutes a predisposition to be sensitive to negative emotional states (Larsen & Ketelaar, 1991).

Finally, our results show an impact of inhibitory capacity on the automatic activation of goal representation. This association could be an example of automatic self-regulation. Fitzsimons and Bargh (2004) argue that operations that are essential to successful self-regulation can also occur without conscious awareness. They cite research on the automatic regulation of cognition, emotion and behaviour and non-conscious goal pursuit as evidence for automatic self-regulation. Fitzsimons and Bargh (2004) conclude that motivational properties of conscious, successful self-regulation could also characterize automatic self-regulation. In our results the impact of inhibitory capacity on goal representation is

automatic insofar as it must not require conscious, intentional intervention. Furthermore, reduced activation of goal representation is a form of adaptation to the demands of the situation (Fitzsimons & Bargh, 2004). Our results suggest that inhibitory capacity could be added to the list of key properties shared by conscious and automatic self-regulation (Segerstrom & Nes, 2007).

Limitations

The study has two limitations regarding the sample. First, sample size was too small to test whether the impact of self-regulatory strength on self-control in the pre- and post-actional phase differs after failure and success experience. Second, the sample included mainly female participants. Women focus more on their negative emotional states than men do (Nolen-Hoeksema & Jackson, 2001). Therefore we expect that the assessed cognitive-affective manifestations of self-control, self-confidence and experienced rumination, be enhanced in our sample compared to a sample including more men. Sex-differences in the impact of self-regulatory strength on cognitive-affective manifestations of self-control in goal-pursuit could not be tested with our sample.

To conclude, our results support the use of tonic HRV as an index for self-regulatory strength in research on self-regulation. An objective measure of self-regulatory strength is useful for research on self-regulatory strength, as people are not aware of and cannot directly report their level of self-regulatory strength.

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